Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx), One Quarter Scale Prototype Thermal Testing

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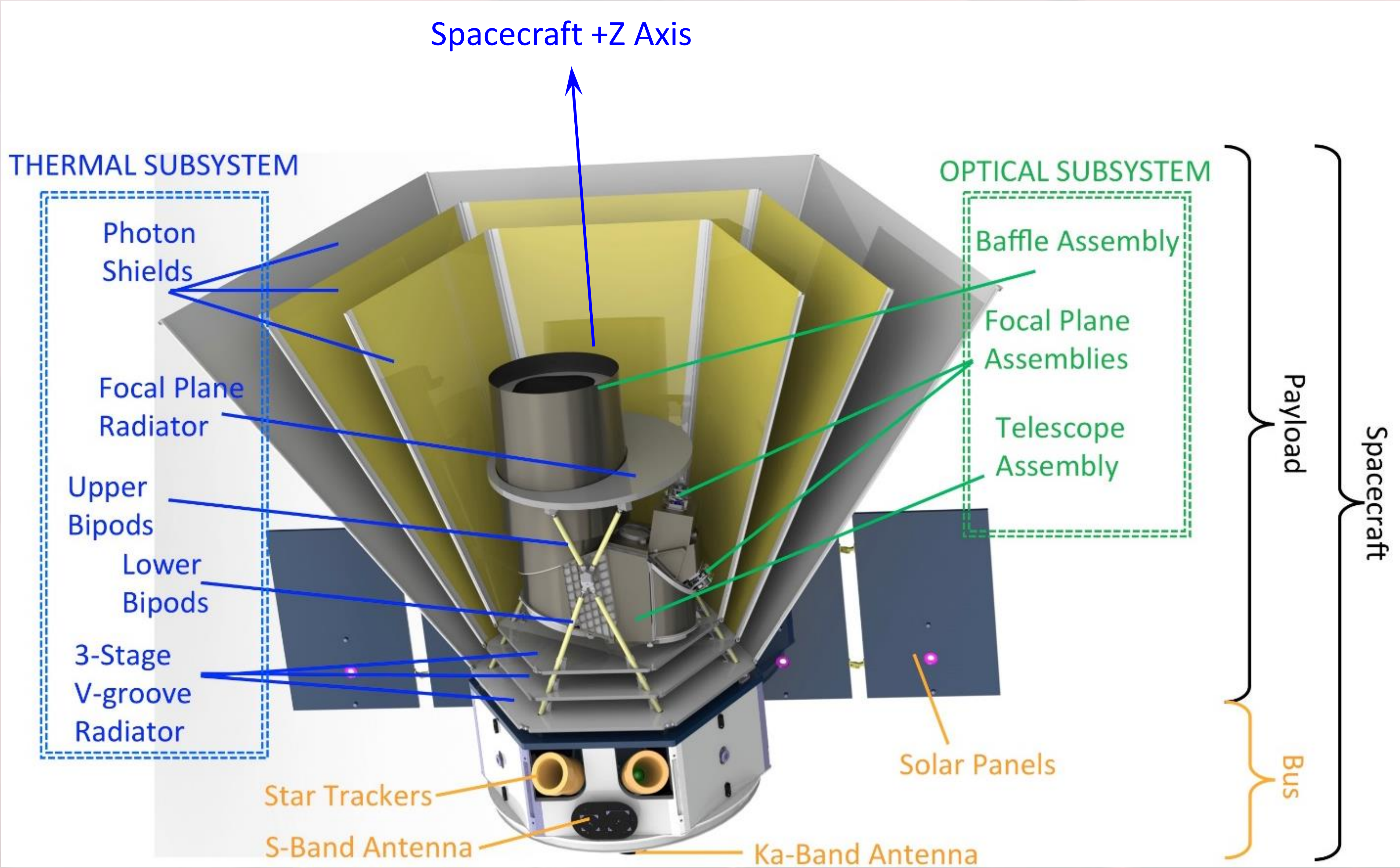
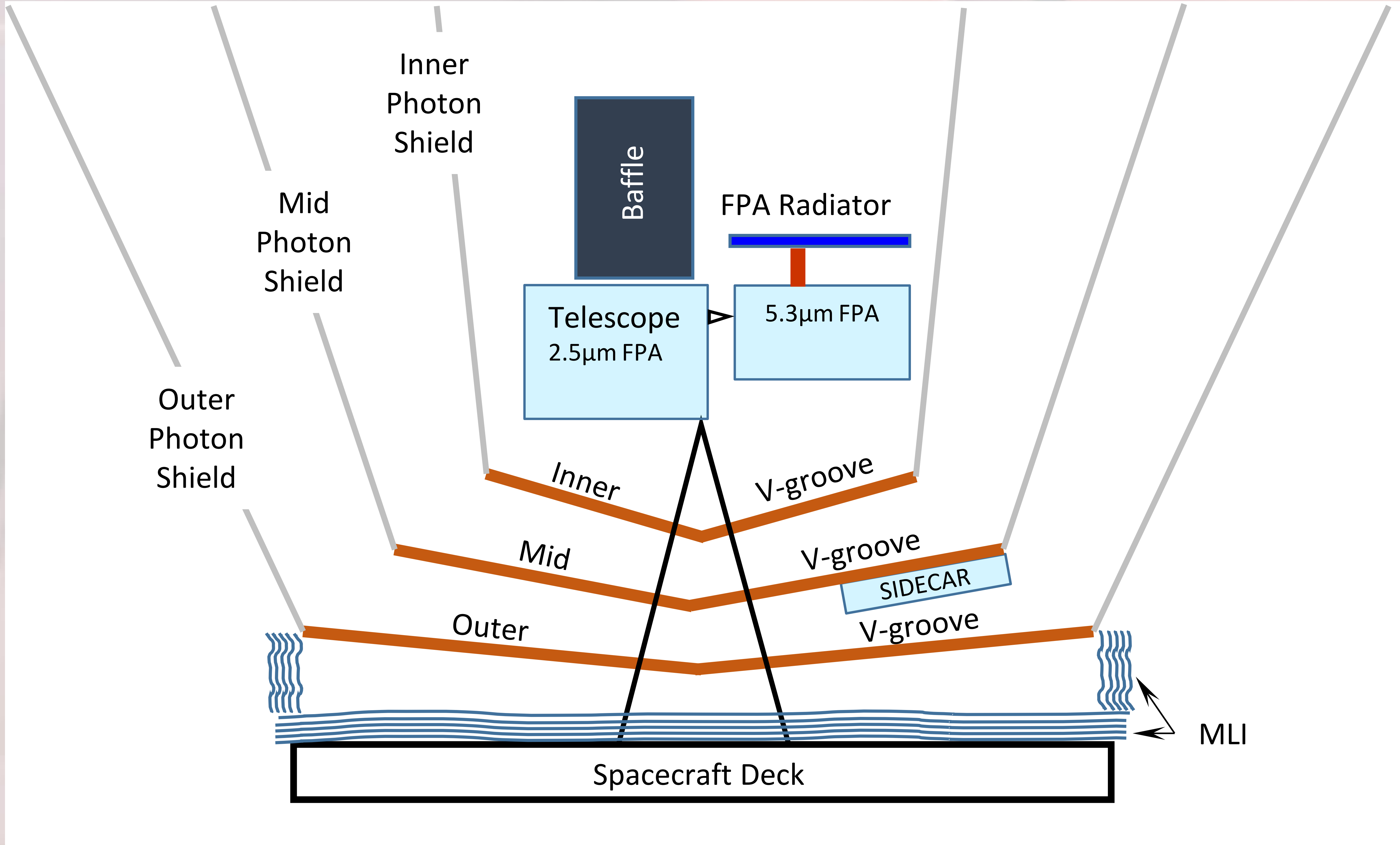
Background, Introduction

- Subscale prototype testing performed to support the SPHEREx proposal effort
  - All-sky near-infrared survey
  - LEO sun-synchronous, 600km orbit
  - Detectors at 55K and 80K
- The paper provides:
  - An overview of the thermal control design approach and the test configuration
  - Test and model correlation results



Instrument Thermal Control Subsystem (1 of 2)

- Five passive radiator stages
  - Three V-groove stages
    - Sequentially extract heat from structure and cables
    - Reject heat to space
  - Telescope body (< 80K)
  - Focal Plane Array (FPA) radiator (< 55K)
- Photon shields extend from the three V-groove stages to provide environmental isolation



Instrument Thermal Control Subsystem (2 of 2)

- V-groove radiators and photon shields utilize specularly reflecting, low emissivity coating
    - Angled relative to adjacent elements to induce energy to reflect out of the system
- Outer surface of outer photon shield uses low solar absorptivity / high infrared emissivity coating
- Telescope body (OBA) acts as fourth radiator stage
    - High infrared emissivity coating
- FPA radiator
    - Open cell honeycomb with high infrared emissivity coating
- Instrument support structure
    - Low thermal conductivity composite

Subscale Prototype Testing

- Means for overcoming some of the drawbacks of full scale thermal vacuum testing
- Some instruments are too large to be tested in existing facilities at full scale
    - James Webb Space Telescope (JWST)
        - 1/3 scale sun shield tests
- Other instruments use scale prototype testing to meet cost constraints
    - Space Infrared Interferometric Telescope (SPIRIT) Origins Probe
        - 18% scale testing

Test Objectives

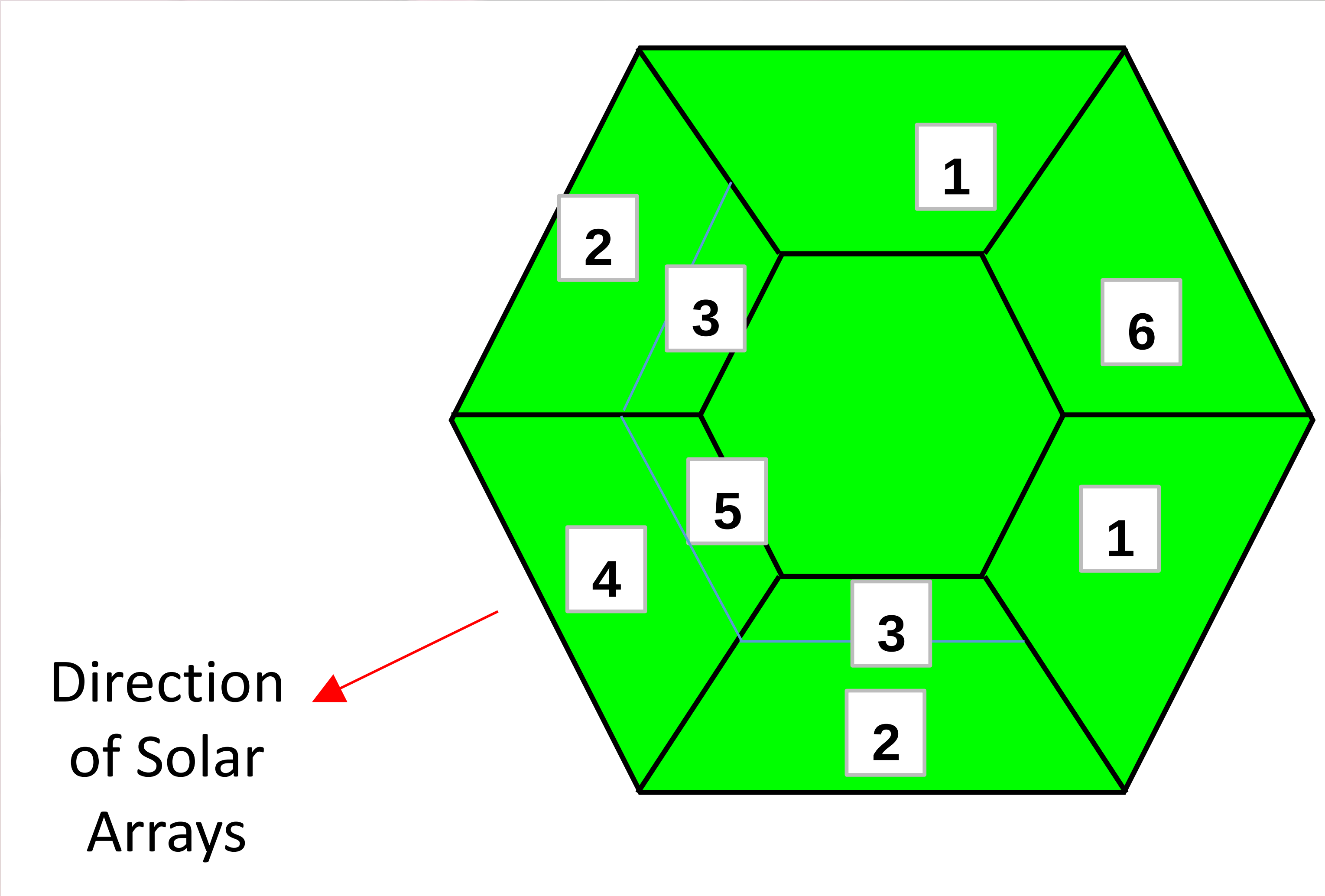
- Identify “unknown unknowns”
    - Bring to light unanticipated issues with the thermal design
- Thermal subsystem design validation
    - Demonstrate that the thermal design performs as required
- Test validated flight thermal models
    - Thermal model correlation updates incorporated into flight thermal models

Test Article (1 of 4)

- Directly derived from full scale flight thermal control subsystem
- Accurate geometry at ¼ scale, flight grade materials
- Dissipations and conduction paths scaled to be consistent with radiative loads
  - Radiation $\propto$ Area = $(1/4)^2$ = 1/16
- Metalized polymer V-groove radiators to match lateral and through conductance at scale
  - Embedded heater simulates Sidecar dissipation
- Manufacturing processes limit scaling of structural support conductance

Test Article (2 of 4)

- Inner and Mid photon shields
  - Polymer film with low emissivity coating on both sides
- Outer photon shield
  - Polymer film with low emissivity coating on inner surface
  - Polymer film with high IR emissivity, low solar absorptivity on outer surface
  - Embedded multi-zoned heater elements provide accurate simulation of environmental and spacecraft heat loads

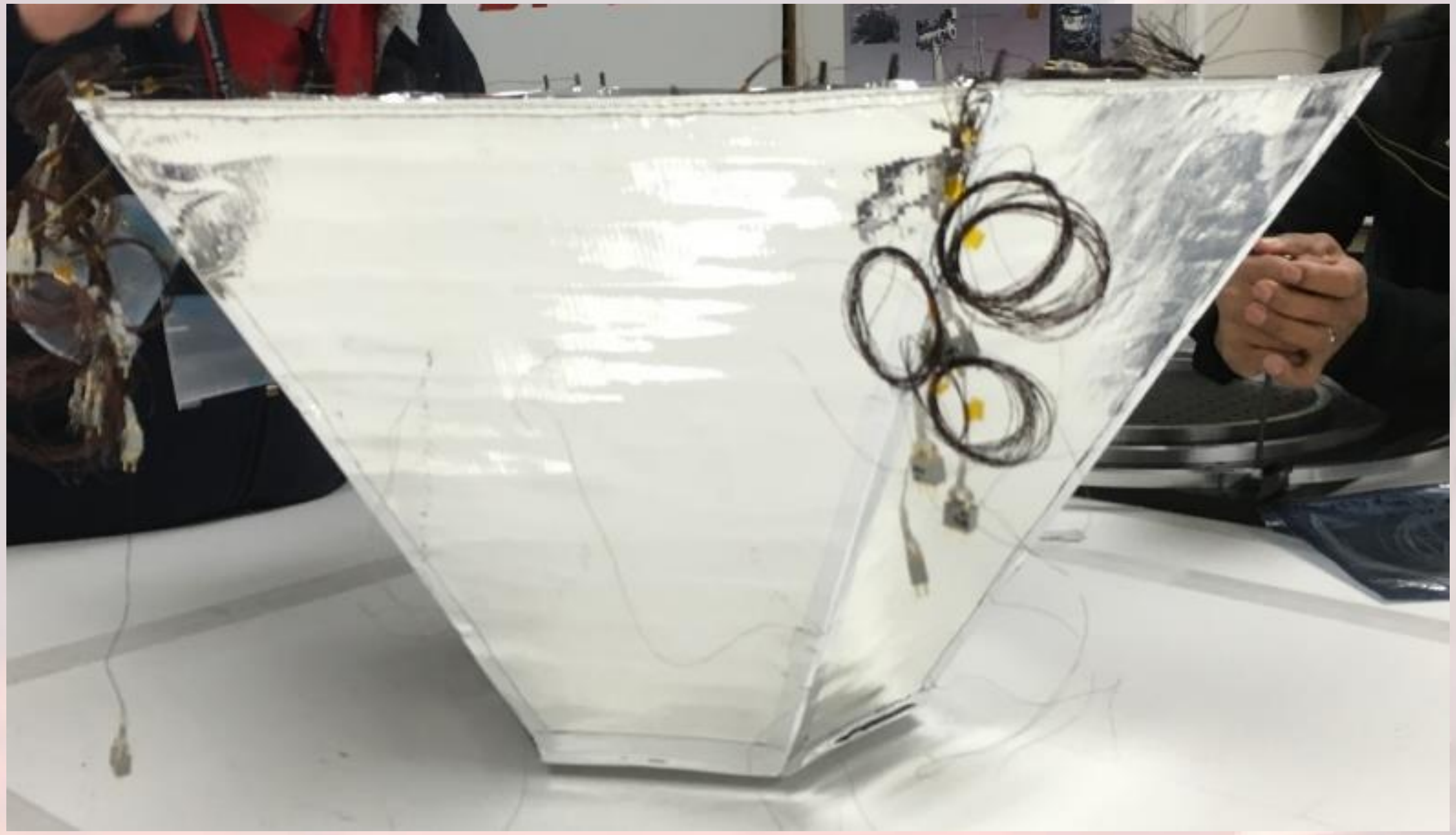


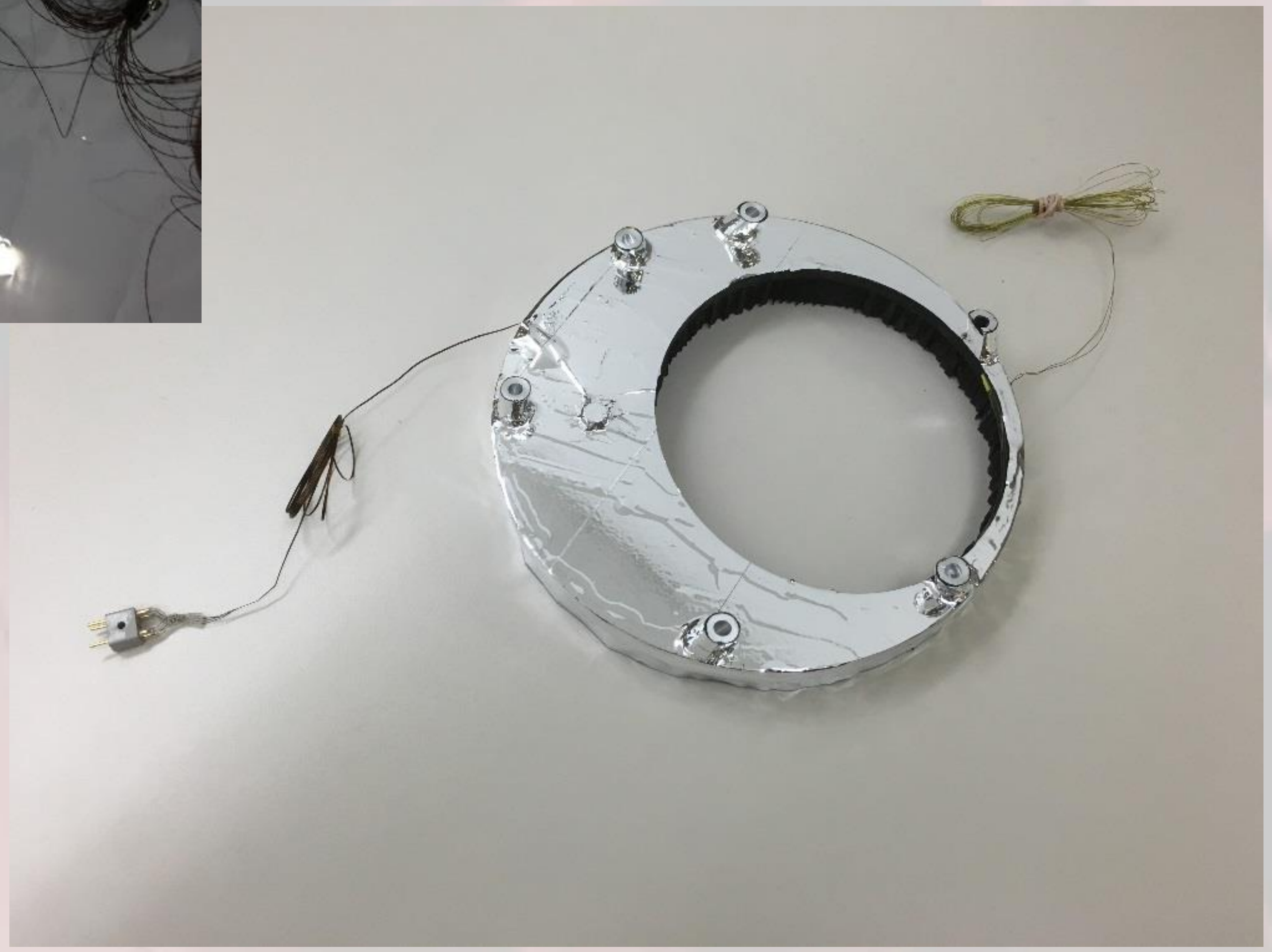
Test Article (3 of 4)

- Telescope body (OBA)
  - Machined from aluminum to scaled flight dimensions
  - Flight like coatings
  - Embedded heater to simulate detector dissipation
- FPA radiator
  - Flight like construction and coatings
  - Embedded heater to simulate detector dissipation

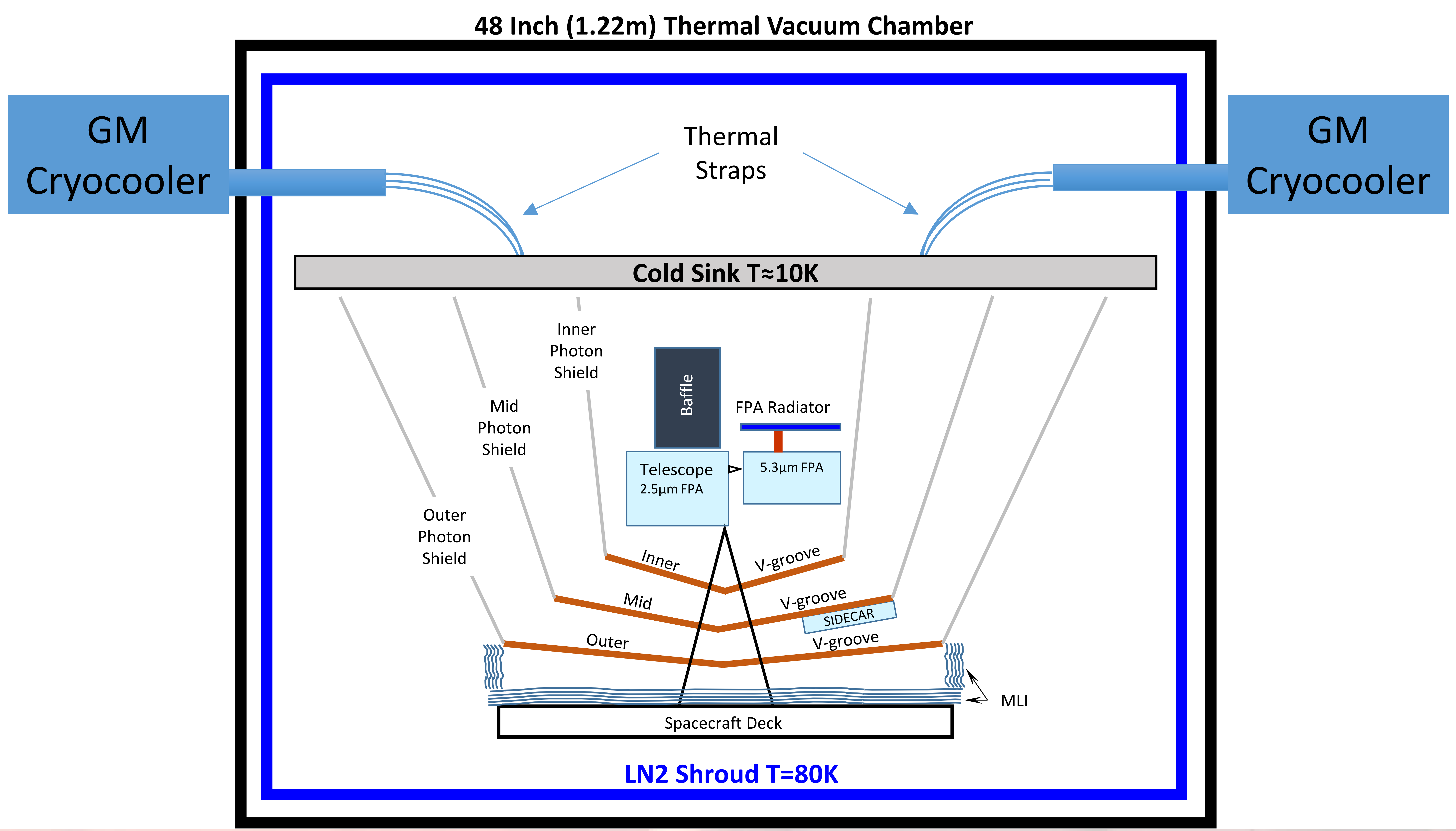
Test Article (4 of 4)

- Fully instrumented with Lakeshore Cryotronics DT-670 diode temperature sensors
- Low conductance Manganin sensor leads



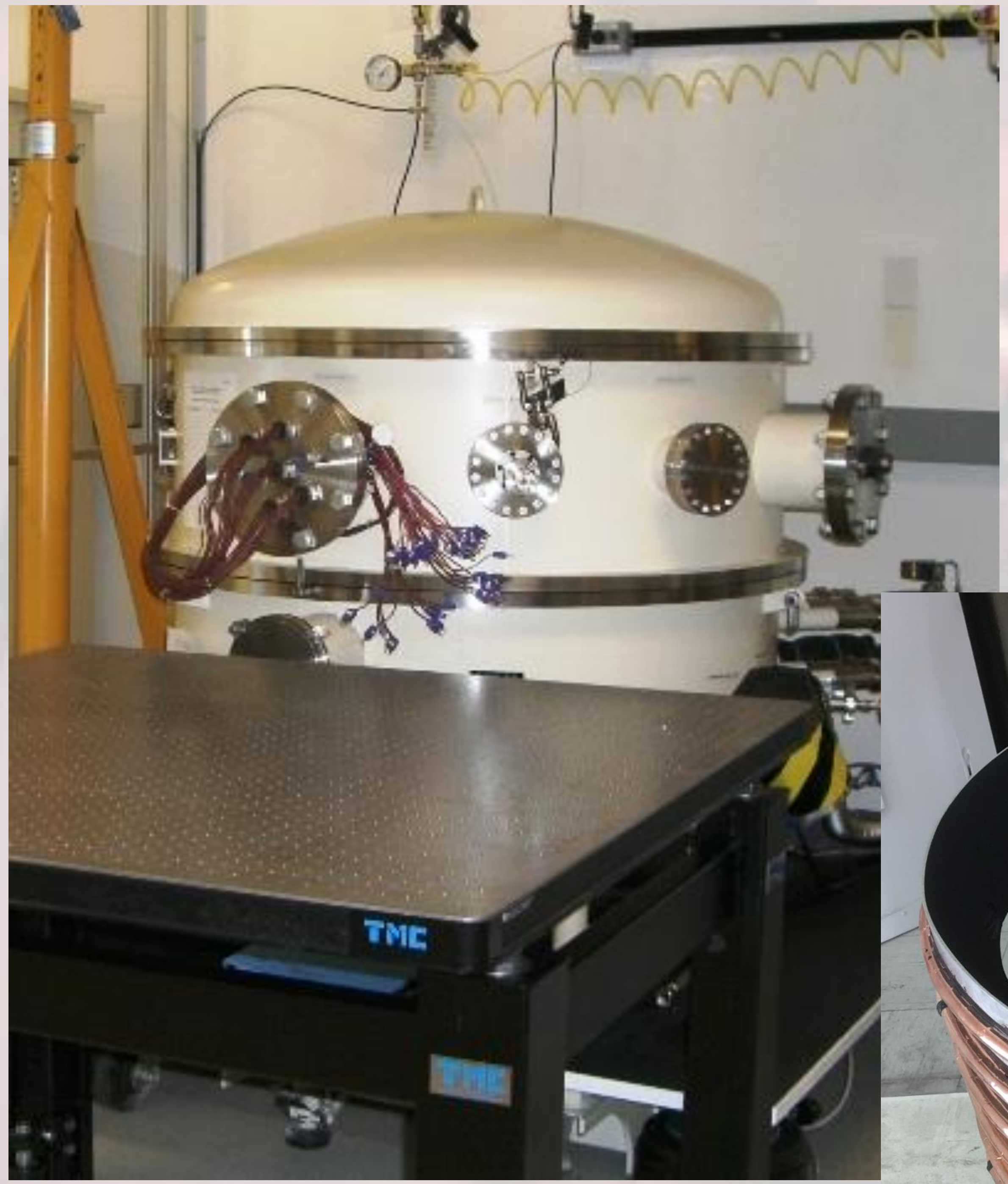


Test Apparatus (1 of 4)



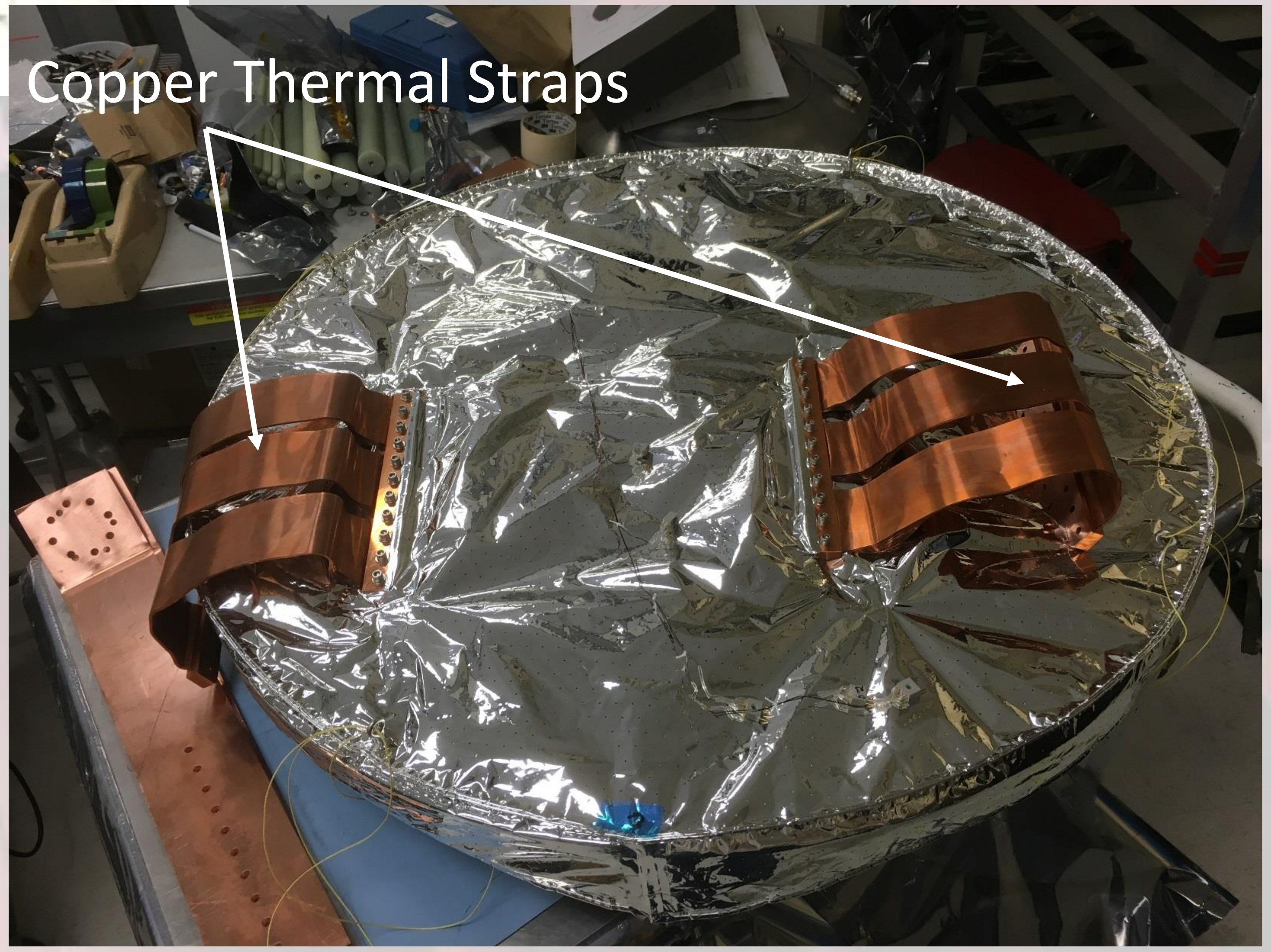
Test Apparatus (2 of 4)

- JPL Advanced Thermal Technology Lab
  - Forty eight inch (1.22m) vacuum chamber
- Liquid nitrogen (LN_2) shroud
  - Separate (LN_2) circuits for top, sides and bottom
  - High emittance internal coating



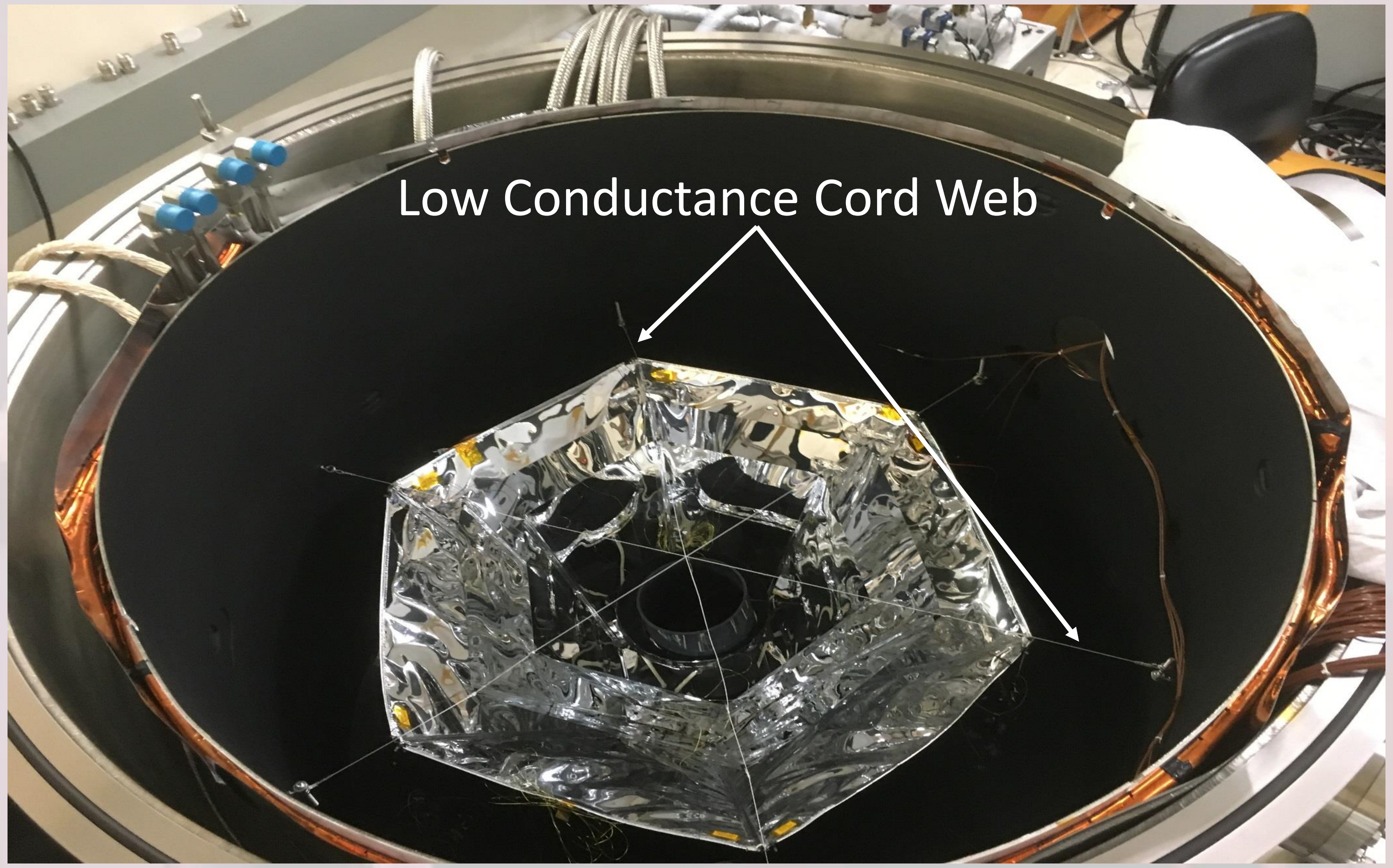
Test Apparatus (3 of 4)

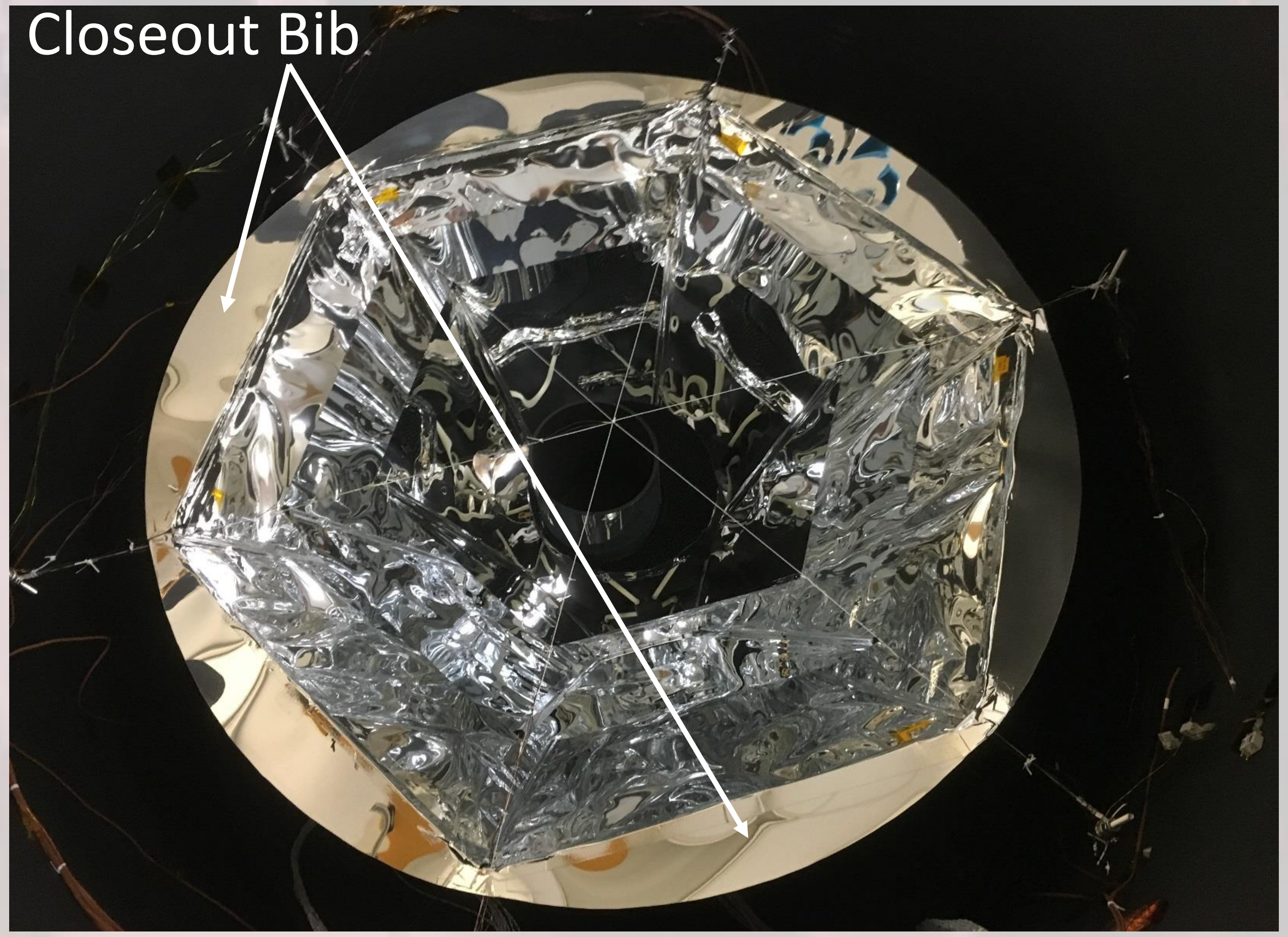
- 10 K cold sink simulates deep space
  - Open cell honeycomb
  - High emissivity coating
  - Back and sides MLI insulated
  - Coupled to Gifford-McMahon cryocoolers with highly conductive copper thermal straps
  - Shimmed to suspend approximately 4mm above the top edge of the photon shields



Test Apparatus (4 of 4)

- Low conductance cord web
  - Used to position photon shield strut tips
  - Provide support for instrumentation and heater leads
    - Allows leads to equilibrate with local radiative environment
- Closeout bib
  - Polymer film with low IR emissivity coating
  - Eliminates unintended radiant energy leak paths





Test Conditions

- Two conditions run to steady state
  - First condition represents expected bounding hot flight case
  - Second condition is the same as the first test condition with FPA radiator heat load sufficient to reach 60K
    - Establishes load margin for FPA radiator

Test Condition	Description	Total Absorbed Photon Shield Heat Load (W)	Average Cold Target Temperature (K)	Average LN2 Shroud Temperature (K)	Simulated 2.5um FPA heat load (mW)	Simulated 5.3um FPA heat load (mW)	Simulated Sidecar heat load (mW)	Spacecraft Simulator Plate Temperature (K)
1	Bounding Hot Environment	66.3	10.9	84.2	1.0	1.0	55.0	286
2	FPA Radiator Power Margin	66.3	10.8	80.3	1.0	9.3	55.0	286

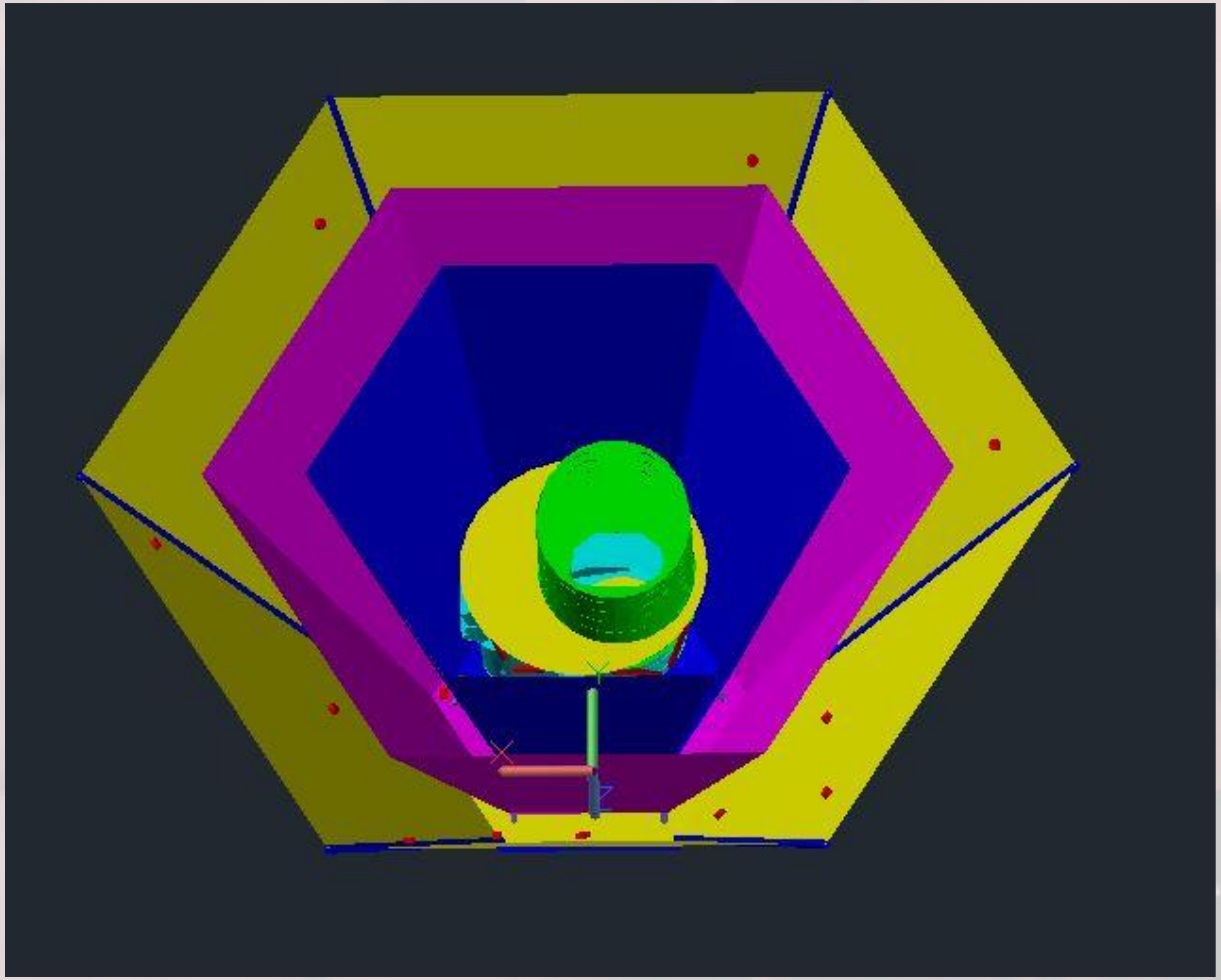
Test Results

- Test results exceed flight system requirements

Table III.C.1, Steady State Test Results			
Test	**Radiator Stage**	**Test Measured Temperature [K]**	**Flight Requirement [K]**
Test Condition 1 Bounding Hot Environment	Outer V-groove radiator panel	235.3	N/A
	Mid V-groove radiator panel	174.4	< 200
	Inner V-groove radiator panel	112.6	N/A
	Telescope Body (OBA)	61.4	< 80
	FPA Radiator	48.7	< 55
Test Condition 2 FPA Radiator Power Margin	Outer V-groove radiator panel	235.3	N/A
	Mid V-groove radiator panel	174.4	< 200
	Inner V-groove radiator panel	112.7	N/A
	Telescope Body (OBA)	61.9	< 80
	FPA Radiator	60.0	< 55

Analytical Modeling

- Test thermal model directly derived from flight thermal model
- Includes relevant test apparatus
  - Liquid nitrogen shroud
  - 10K cold sink
  - Test instrumentation
- Thermal Desktop



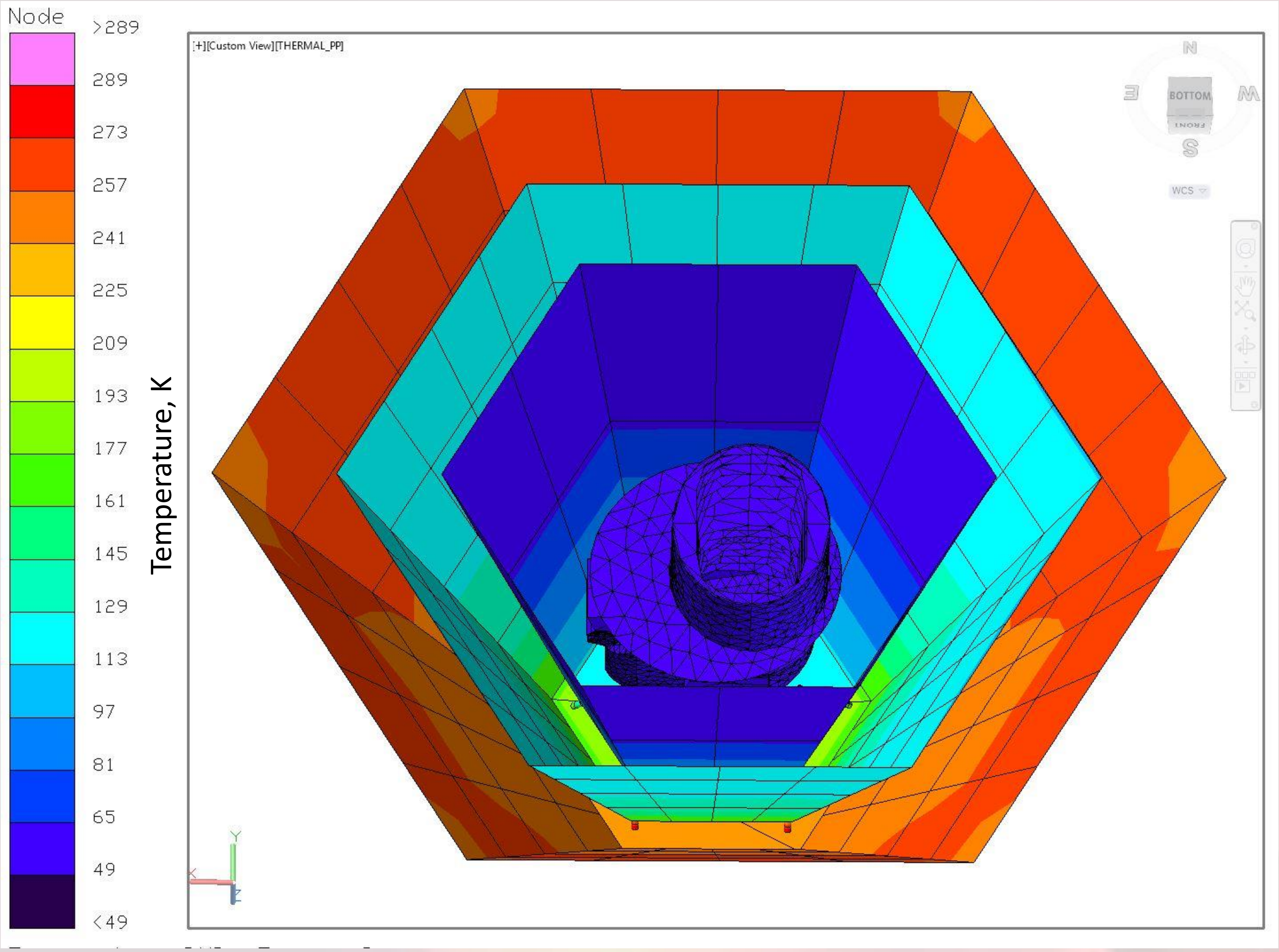
Correlated Model (1 of 3)

- Successful correlation with agreement to both test conditions to 1K at critical radiator stages
- All correlation changes incorporated into flight models

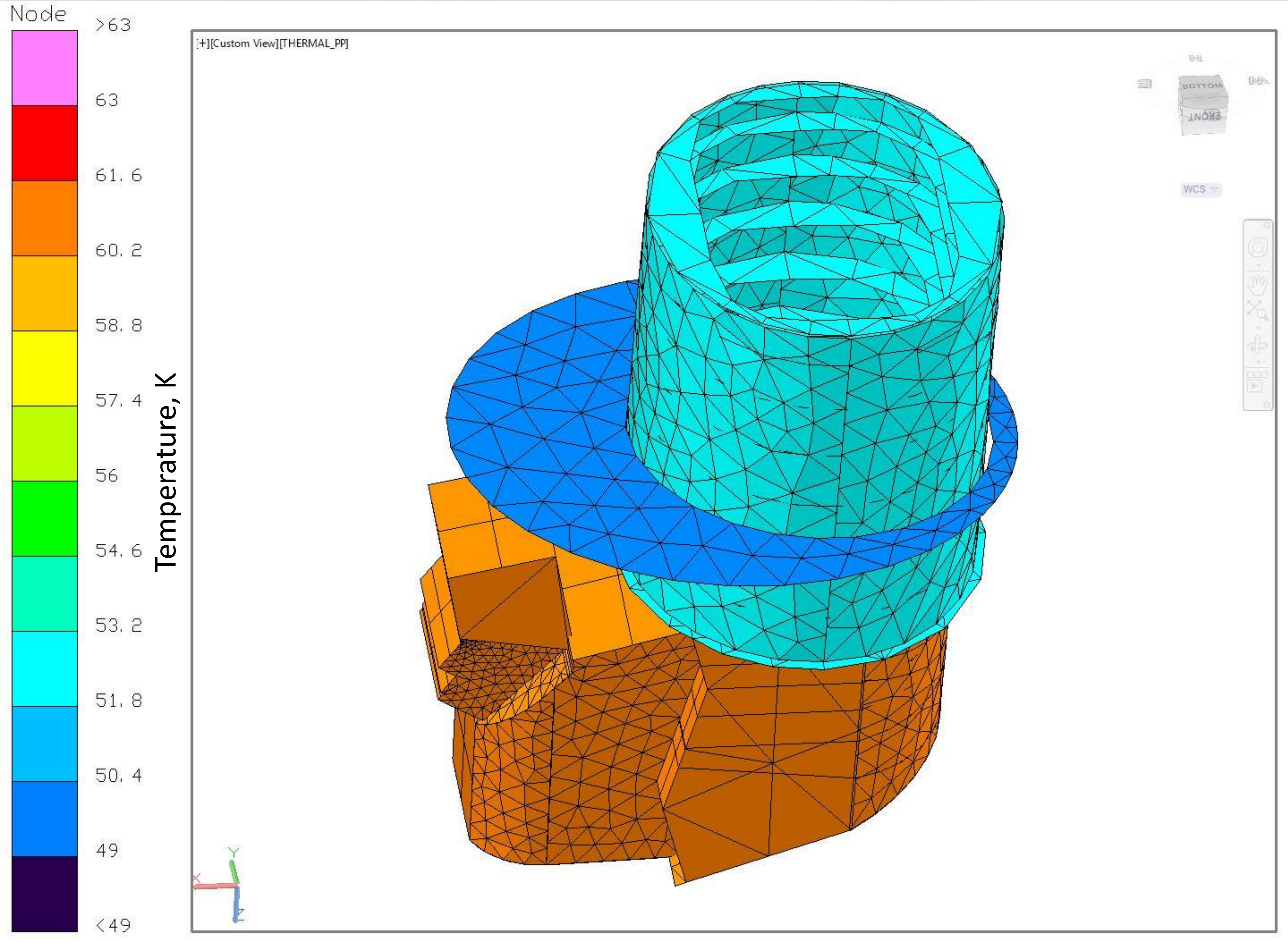
Table IV.1, Comparison of Test Measured Temperatures to Model Predictions

Test	Radiator Stage	Test Measured Temperature [K]	Correlated Model Prediction [K]	Applied Power [mW]
Test Condition 1 Bounding Hot Environment	Outer V-groove radiator panel	235.3	235.9	N/A
	Mid V-groove radiator panel	174.4	174.1	55.0
	Inner V-groove radiator panel	112.6	113.1	0
	Telescope Body (OBA)	61.4	61.0	1.0
	FPA Radiator	48.7	49.3	1.0
Test Condition 2 FPA Radiator Power Margin	Outer V-groove radiator panel	235.3	235.9	N/A
	Mid V-groove radiator panel	174.4	174.1	55.0
	Inner V-groove radiator panel	112.7	113.1	0.0
	Telescope Body (OBA)	61.9	62.8	1.0
	FPA Radiator	60.0	59.6	9.3

Correlated Model (2 of 3)

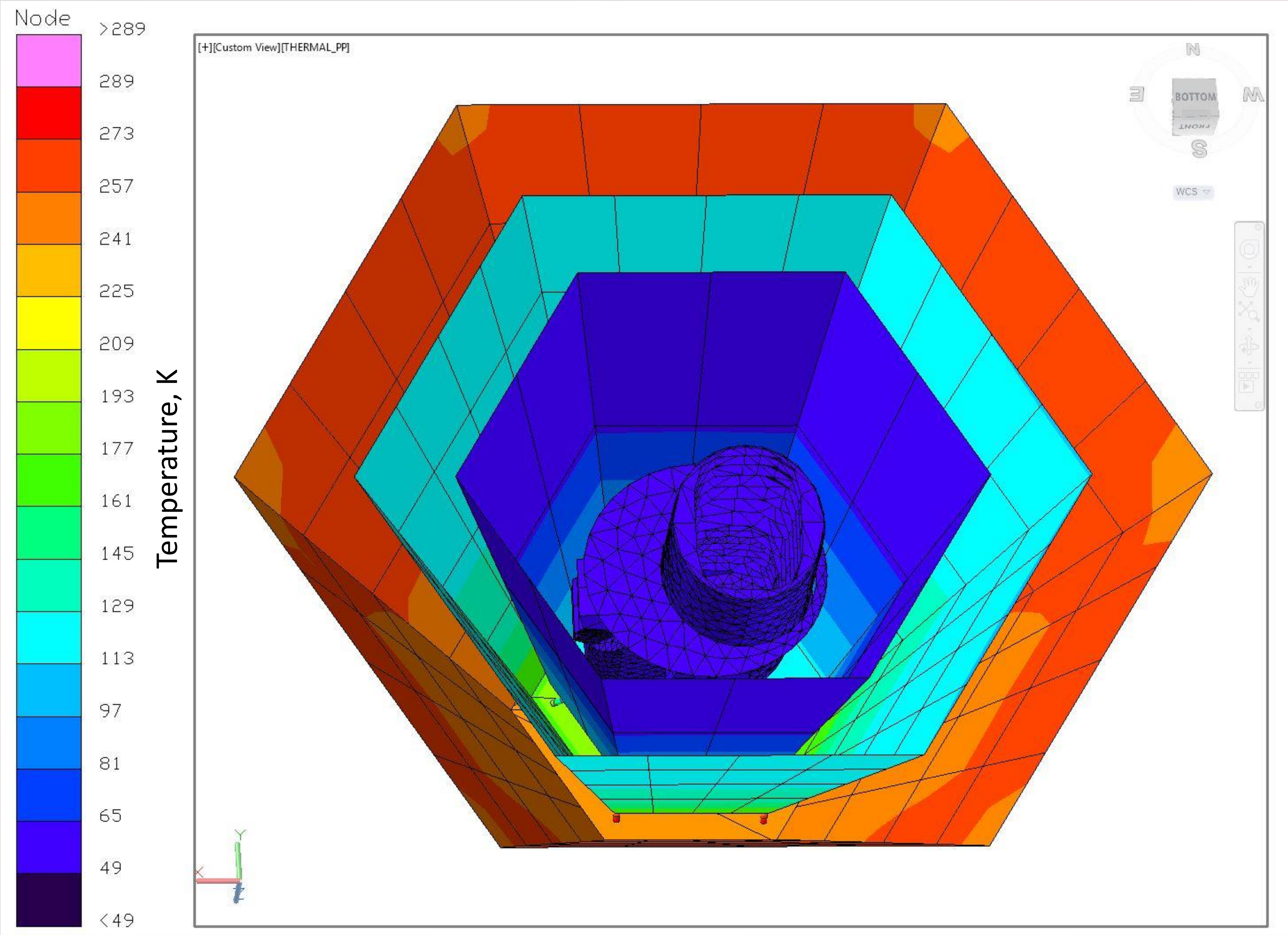


Test Condition 1
Instrument Temperature Map

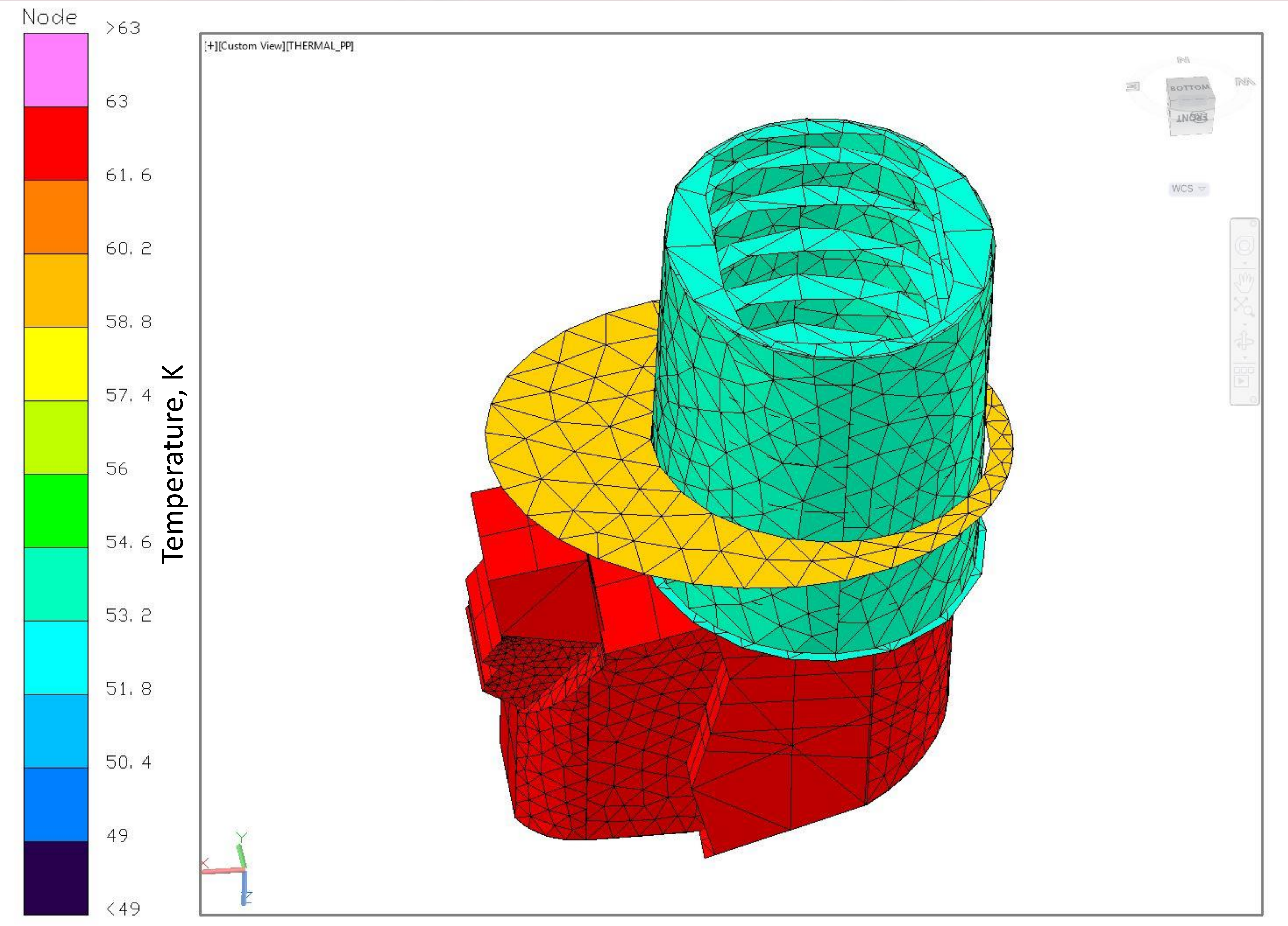


Test Condition 1
Telescope, Baffle and FPA Radiator Temperature Map

Correlated Model (3 of 3)



Test Condition 2
Instrument Temperature Map



Test Condition 2
Telescope, Baffle and FPA Radiator Temperature Map

Summary / Conclusions

- Test objectives met
    - No unanticipated issues
    - Thermal subsystem design meets instrument requirements
        - Provides a level of flight thermal design validation
    - Test thermal model correlation changes incorporated into flight thermal model
        - Flight thermal models validated through testing

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